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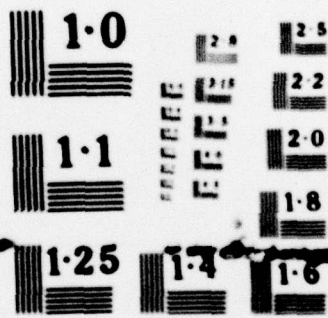UNCLASSIFIED   NOSC-TD-270   F/G 8/1

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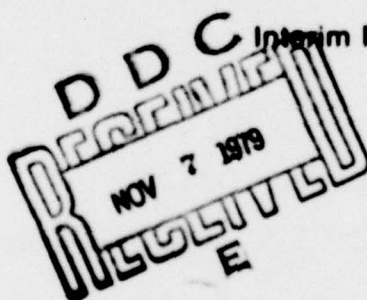# THERMAL-NOISE LIMIT IN DELPHINID HEARING

C Scott Johnson

June 1979

Interim Report: January 1978 — April 1979

Prepared for
Naval Material Command

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SAN DIEGO, CALIFORNIA 92152

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In quiet experimental tanks, thermal noise is the dominant noise source above 50 kHz. Evidence indicates that in the frequency range above 50 kHz cetacean auditory thresholds are limited by thermal noise. Data were compared for Tursiops, Phocoena, Inia, and Delphinapterus.

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Several species of small whales have been shown to have excellent hearing above 50 kHz (Fig. 1). Making threshold measurements on cetaceans is very difficult. Apart from the behavioral difficulties involved, the measurement of the acoustic field has to be approximated. This is because the experiments are, of necessity, performed in tanks or lagoons that are not anechoic. Standing waves cause the sound level to vary above and below the average measured levels. Standing waves increase the detectability of the sound field by a factor equal to the standing wave ratio (SWR) (Ref. 1). The SWR is equal to the ratio of the maximum field pressure level to the minimum field pressure level. A SWR of a little over three would increase the detectability of a tone by 10 dB, and SWRs of three or more are not difficult to achieve under experimental conditions such as those used in the threshold experiments. Calibrations are made without the animal present and the effect of the animal's presence on the sound field is never known. No one has yet been heroic enough to try to put earphones on a dolphin. In addition, the sound level at the animal's ear is impossible to determine because they have no external auditory meatus. In the past we have just done the best we could, believing that some not too accurate data were better than none. We have now collected enough data to show that an interesting pattern has developed, and they may point the way to more accurate measurements.

Above about 50 kHz the noise spectrum underwater is dominated by thermal noise (Ref. 2). The slope of the spectrum is always the same for a given absolute temperature and acoustic impedance. Shown plotted in Fig. 1 is the theoretical thermal noise spectrum in the cochlear fluid of an animal whose deep body temperature is 37°C (310°K), assuming that the cochlear fluid has the same acoustic impedance as water. The temperature of the cochlear fluid is always greater and therefore contributes more noise than the surrounding water. However, this spectrum is not very sensitive to temperature because only absolute temperature enters the equation. Using a temperature of 10°C (283°K) only lowers the spectrum by about 1 dB.

According to Fletcher's 1940 critical-band theory (Ref. 10), only a relatively narrow band of noise frequencies (the critical-band) is effective in masking a tonal signal. Expressed in another way, the limiting threshold at a given frequency due to noise is the sum of the noise level per hertz and the critical ratio expressed in decibels. The critical ratios measured for the Atlantic bottlenosed porpoise *Tursiops truncatus* (Ref. 5), are shown plotted in Figure 2. Also shown in Figure 2 are the values obtained by Thompson and Herman (Ref. 11) for the minimum perceptible frequency change in *T. truncatus*. These two sets of data have been plotted on scales shifted by a factor of 20 to show the similarity with the results reported by Fletcher (Ref. 10) for human subjects. The open circles in Figure 2 are the values of the minimum perceptible change in frequencies for the harbor porpoise *(Phocoena phocoena)* measured by Sukhoruchenko (Ref. 12), the only other cetacean for which these data are available.

In Figure 1 the sum of the critical ratio and the thermal noise spectrum is shown plotted as the crosshatched area in the figure. The width of the crosshatched area corresponds to the spread in the critical ratio data shown between the dashed lines in Figure 2. Only two points from the *P. phocoena* data, those at 45 and 90 kHz, fall within the frequency range from 50 to 100 kHz. On the assumption that the factor of 20 between critical ratios and DLs hold for *P. phocoena*, the thresholds at these two frequencies are plotted in Figure 1. The two points are shown connected by a straight line.
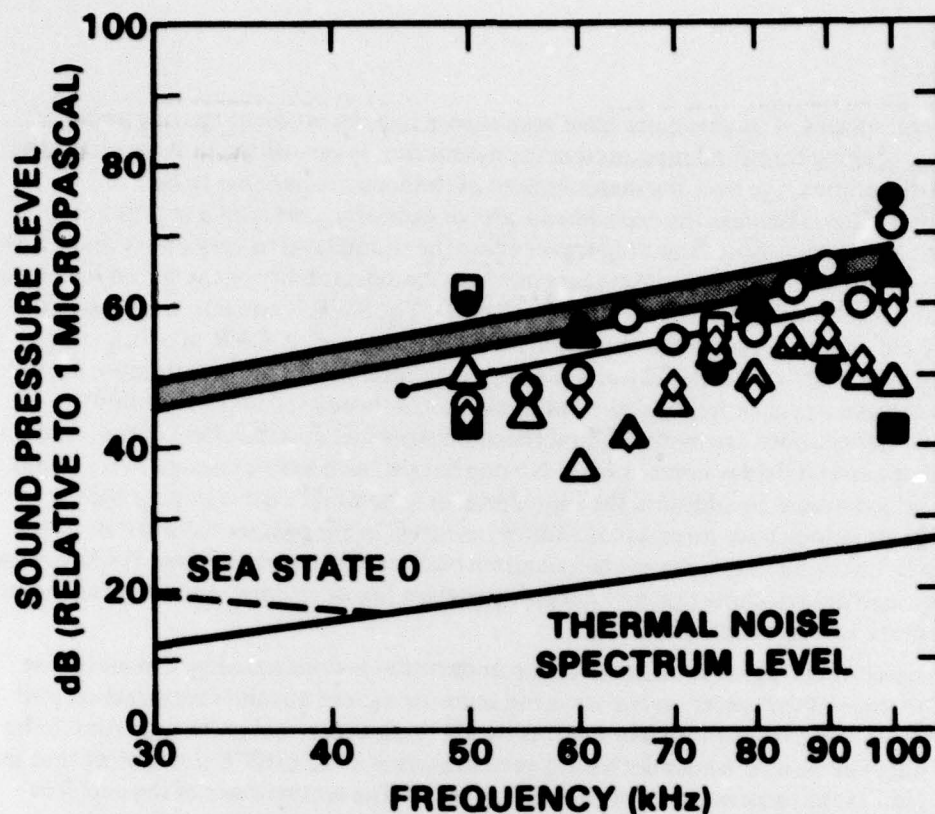
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Figure 1. Plot of the auditory thresholds measured using training techniques for eight individuals of five delphinid species: diamonds, *T. truncatus* (Ref. 3); open squares, *T. truncatus* (Ref. 4); closed squares, *T. truncatus* (Ref. 5); closed circles, *I. geoffrensis* (Ref. 6); open circles, *T. gilli* (Ref. 7); closed triangles, *P. phocoena* (Ref. 8); open triangles, *D. Leucas* (Ref. 9). The crosshatched area represents the estimated minimum threshold due to thermal noise masking using critical ratios measured for *T. truncatus*. The two points connected by the solid straight line represent a similar limit determined from data on *P. phocoena*.

While there is considerable variability in the threshold values plotted in Figure 1, almost all points fall below the minimum predicted by adding the thermal noise to the critical ratio, the average being about 10 dB lower. This includes the thresholds measured for the same *T. truncatus* used for the critical ratio experiment. One can only conclude that either the thresholds or critical ratios or both are somewhat in error, at least for *T. truncatus*. In the other species the critical ratios may be smaller. A decrease of 10 dB in the critical ratios would be a reduction by a factor of ten. Unfortunately critical ratios have been measured for only one *T. truncatus*.

In spite of inaccuracies in the data, the evidence is consistent with the conclusion that above 50 kHz, the thresholds of at least *T. truncatus* are masked by thermal noise. This is an important conclusion because, if true, a way is available to make accurate threshold measurements, at least at frequencies above 50 kHz, where thermal noise dominates, and of

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course below the upper hearing limit, where other factors limit hearing. In this case absolute thresholds could be determined by measuring critical ratios and estimating thresholds by means of calculated thermal noise levels. This is an attractive method because the thermal noise spectrum depends only on the animal's body temperature, which is essentially constant either in or out of water, and critical ratio measurements do not require absolute sound level determinations.

The evidence presented here for cetacean hearing thresholds being masked by thermal noise is circumstantial. Better data are clearly needed. Thus far critical ratios have been measured on only one animal of one species. They need to be redetermined for *T. truncatus* and for other species as well. If these measurements support the present values, a new and better way may be available for determining absolute thresholds in cetaceans.
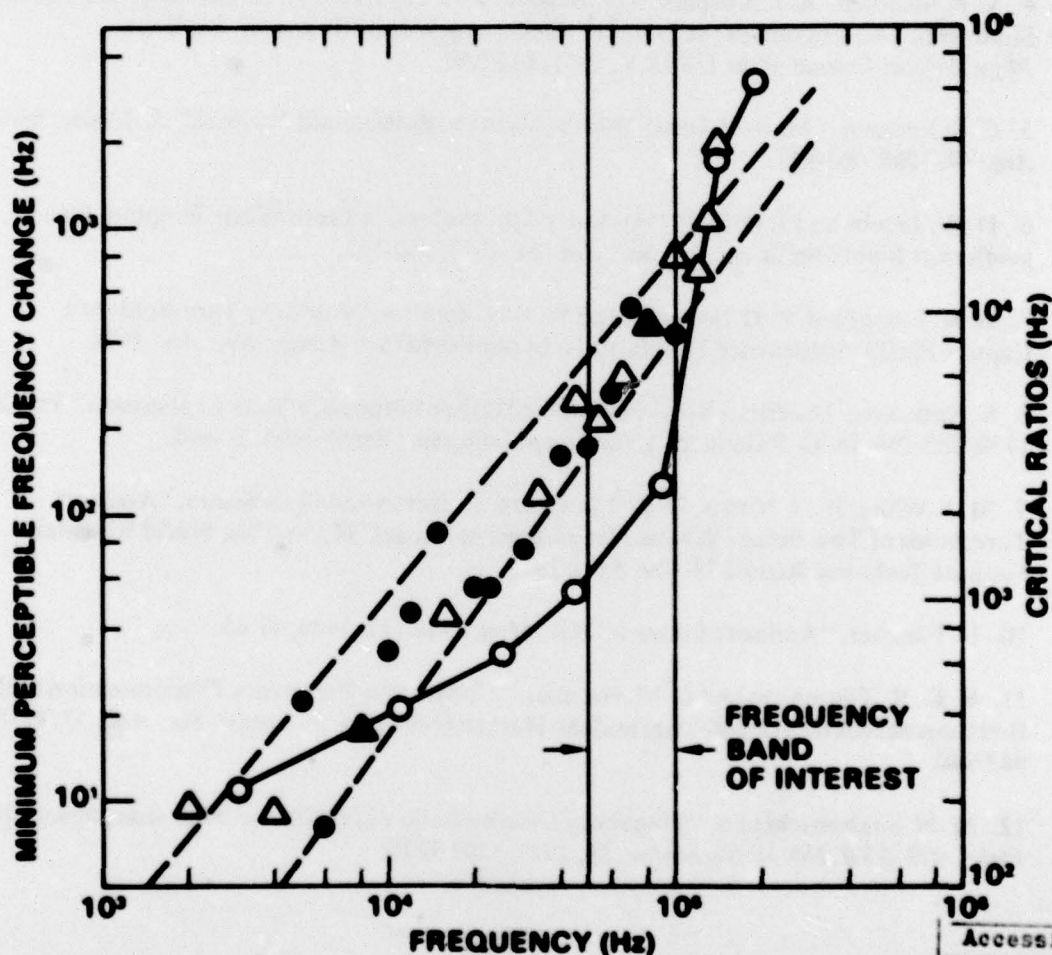

Figure 2. The closed circles are the critical ratio values for *T. truncatus*, the open triangles are the frequency difference limens from *T. truncatus*, the open circles are the minimum perceptible frequency limens for *P. phocoena*. The left-hand ordinate gives the minimum perceptible frequency change in hertz shifted down by a factor of 20 from the right-hand ordinate, which gives the critical ratios in hertz.

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